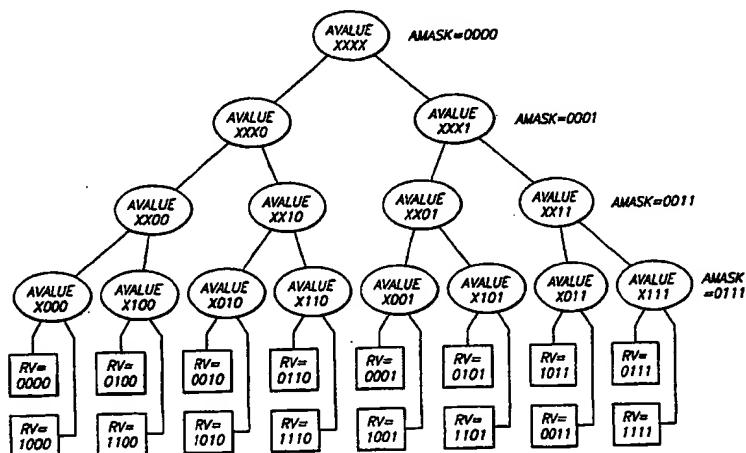




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(54) Title: METHOD OF IDENTIFYING WIRELESS UNITS



## (57) Abstract

A method of establishing wireless communications between an interrogator and individual ones of multiple wireless identification devices, the method comprising utilizing a tree search method to establish communications without collision between the interrogator and individual ones of the multiple wireless identification devices, a search tree being defined for the tree search method, the tree having multiple levels respectively representing subgroups of the multiple wireless identification devices, the method further comprising starting the tree search at a selectable level of the search tree. A communications system comprising an interrogator, and a plurality of wireless identification devices configured to communicate with the interrogator in a wireless fashion, the respective wireless identification devices having a unique identification number, the interrogator being configured to employ a tree search technique to determine the unique identification numbers of the different wireless identification devices so as to be able to establish communications between the interrogator and individual ones of the multiple wireless identification devices without collision by multiple wireless identification devices attempting to respond to the interrogator at the same time, wherein the interrogator is configured to start the tree search at a selectable level of the search tree.

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**METHOD OF IDENTIFYING WIRELESS UNITS****5    Technical Field**

This invention relates to communications protocols and to digital data communications. Still more particularly, the invention relates to data communications protocols in mediums such as radio communication or the like. The invention also relates to radio frequency identification devices for  
10    inventory control, object monitoring, determining the existence, location or movement of objects, or for remote automated payment.

**Background Art**

Communications protocols are used in various applications. For  
15    example, communications protocols can be used in electronic identification systems. As large numbers of objects are moved in inventory, product manufacturing, and merchandising operations, there is a continuous challenge to accurately monitor the location and flow of objects. Additionally, there is a continuing goal to interrogate the location of objects in an inexpensive  
20    and streamlined manner. One way of tracking objects is with an electronic identification system.

One presently available electronic identification system utilizes a magnetic coupling system. In some cases, an identification device may be provided with a unique identification code in order to distinguish between a  
25    number of different devices. Typically, the devices are entirely passive (have no power supply), which results in a small and portable package. However, such identification systems are only capable of operation over a relatively short range, limited by the size of a magnetic field used to supply power to the devices and to communicate with the devices.

30    Another wireless electronic identification system utilizes a large active transponder device affixed to an object to be monitored which receives a signal from an interrogator. The device receives the signal, then generates

and transmits a responsive signal. The interrogation signal and the responsive signal are typically radio-frequency (RF) signals produced by an RF transmitter circuit. Because active devices have their own power sources, and do not need to be in close proximity to an interrogator or reader to receive power via magnetic coupling. Therefore, active transponder devices tend to be more suitable for applications requiring tracking of a tagged device that may not be in close proximity to an interrogator. For example, active transponder devices tend to be more suitable for inventory control or tracking.

Electronic identification systems can also be used for remote payment. For example, when a radio frequency identification device passes an interrogator at a toll booth, the toll booth can determine the identity of the radio frequency identification device, and thus of the owner of the device, and debit an account held by the owner for payment of toll or can receive a credit card number against which the toll can be charged. Similarly, remote payment is possible for a variety of other goods or services.

A communication system typically includes two transponders: a commander station or interrogator, and a responder station or transponder device which replies to the interrogator.

If the interrogator has prior knowledge of the identification number of a device which the interrogator is looking for, it can specify that a response is requested only from the device with that identification number. Sometimes, such information is not available. For example, there are occasions where the interrogator is attempting to determine which of multiple devices are within communication range.

When the interrogator sends a message to a transponder device requesting a reply, there is a possibility that multiple transponder devices will attempt to respond simultaneously, causing a collision, and thus causing an erroneous message to be received by the interrogator. For example, if the interrogator sends out a command requesting that all devices within a communications range identify themselves, and gets a large number of simultaneous replies, the interrogator may not be able to interpret any of

these replies. Thus, arbitration schemes are employed to permit communications free of collisions.

In one arbitration scheme or system, described in commonly assigned U.S. Patent Nos. 5,627,544; 5,583,850; 5,500,650; and 5,365,551, all to  
5 Snodgrass et al. and all incorporated herein by reference, the interrogator sends a command causing each device of a potentially large number of responding devices to select a random number from a known range and use it as that device's arbitration number. By transmitting requests for identification to various subsets of the full range of arbitration numbers,  
10 and checking for an error-free response, the interrogator determines the arbitration number of every responder station capable of communicating at the same time. Therefore, the interrogator is able to conduct subsequent uninterrupted communication with devices, one at a time, by addressing only one device.

15 Another arbitration scheme is referred to as the Aloha or slotted Aloha scheme. This scheme is discussed in various references relating to communications, such as Digital Communications: Fundamentals and Applications, Bernard Sklar, published January 1988 by Prentice Hall. In this type of scheme, a device will respond to an interrogator using one of many  
20 time domain slots selected randomly by the device. A problem with the Aloha scheme is that if there are many devices, or potentially many devices in the field (i.e. in communications range, capable of responding) then there must be many available slots or many collisions will occur. Having many available slots slows down replies. If the magnitude of the number of devices  
25 in a field is unknown, then many slots are needed. This results in the system slowing down significantly because the reply time equals the number of slots multiplied by the time period required for one reply.

An electronic identification system which can be used as a radio frequency identification device, arbitration schemes, and various applications  
30 for such devices are described in detail in commonly assigned U.S. Patent Application Serial Number 08/705,043, filed August 29, 1996, and incorporated herein by reference.

**Disclosure of the Invention**

The invention provides a wireless identification device configured to provide a signal to identify the device in response to an interrogation signal.

One aspect of the invention provides a method of establishing wireless  
5 communications between an interrogator and individual ones of multiple  
wireless identification devices. The method comprises utilizing a tree search  
method to establish communications without collision between the interrogator  
and individual ones of the multiple wireless identification devices. A search  
tree is defined for the tree search method. The tree has multiple levels  
10 respectively representing subgroups of the multiple wireless identification  
devices. The method further comprising starting the tree search at a  
selectable level of the search tree. In one aspect of the invention, the  
method further comprises determining the maximum possible number of  
wireless identification devices that could communicate with the interrogator,  
15 and selecting a level of the search tree based on the determined maximum  
possible number of wireless identification devices that could communicate with  
the interrogator. In another aspect of the invention, the method further  
comprises starting the tree search at a level determined by taking the base  
two logarithm of the determined maximum possible number, wherein the level  
20 of the tree containing all subgroups is considered level zero, and lower levels  
are numbered consecutively.

Another aspect of the invention provides a communications system  
comprising an interrogator, and a plurality of wireless identification devices  
configured to communicate with the interrogator in a wireless fashion. The  
25 respective wireless identification devices have a unique identification number.  
The interrogator is configured to employ a tree search technique to  
determine the unique identification numbers of the different wireless  
identification devices so as to be able to establish communications between  
the interrogator and individual ones of the multiple wireless identification  
30 devices without collision by multiple wireless identification devices attempting  
to respond to the interrogator at the same time. The interrogator is  
configured to start the tree search at a selectable level of the search tree.

One aspect of the invention provides a radio frequency identification device comprising an integrated circuit including a receiver, a transmitter, and a microprocessor. In one embodiment, the integrated circuit is a monolithic single die single metal layer integrated circuit including the receiver, the transmitter, and the microprocessor. The device of this embodiment includes an active transponder, instead of a transponder which relies on magnetic coupling for power, and therefore has a much greater range.

### **Brief Description of the Drawings**

Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

Fig. 1 is a high level circuit schematic showing an interrogator and a radio frequency identification device embodying the invention.

Fig. 2 is a front view of a housing, in the form of a badge or card, supporting the circuit of Fig. 1 according to one embodiment the invention.

Fig. 3 is a front view of a housing supporting the circuit of Fig. 1 according to another embodiment of the invention.

Fig. 4 is a diagram illustrating a tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

Fig 5. is a diagram illustrating a modified tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

Fig. 6 is a diagram illustrating a modified tree splitting sort method for establishing communications with a radio frequency identification device in a field of a plurality of such devices.

Fig. 7 is a diagram illustrating a modified tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

**Best Modes for Carrying Out the Invention and Disclosure of Invention**

Fig. 1 illustrates a wireless identification device 12 in accordance with one embodiment of the invention. In the illustrated embodiment, the wireless identification device is a radio frequency data communication device 12, and includes RFID circuitry 16. The device 12 further includes at least one antenna 14 connected to the circuitry 16 for wireless or radio frequency transmission and reception by the circuitry 16. In the illustrated embodiment, the RFID circuitry is defined by an integrated circuit as described in the above-incorporated patent application 08/705,043, filed August 29, 1996. Other embodiments are possible. A power source or supply 18 is connected to the integrated circuit 16 to supply power to the integrated circuit 16. In one embodiment, the power source 18 comprises a battery.

The device 12 transmits and receives radio frequency communications to and from an interrogator 26. An exemplary interrogator is described in commonly assigned U.S. Patent Application Serial No. 08/907,689, filed August 8, 1997 and incorporated herein by reference. Preferably, the interrogator 26 includes an antenna 28, as well as dedicated transmitting and receiving circuitry, similar to that implemented on the integrated circuit 16.

Generally, the interrogator 26 transmits an interrogation signal or command 27 via the antenna 28. The device 12 receives the incoming interrogation signal via its antenna 14. Upon receiving the signal 27, the device 12 responds by generating and transmitting a responsive signal or reply 29. The responsive signal 29 typically includes information that uniquely identifies, or labels the particular device 12 that is transmitting, so as to identify any object or person with which the device 12 is associated.

Although only one device 12 is shown in Fig. 1, typically there will be multiple devices 12 that correspond with the interrogator 26, and the particular devices 12 that are in communication with the interrogator 26 will typically change over time. In the illustrated embodiment in Fig. 1, there is no communication between multiple devices 12. Instead, the devices 12 respectively communicate with the interrogator 26. Multiple devices 12 can



be used in the same field of an interrogator 26 (i.e., within communications range of an interrogator 26).

The radio frequency data communication device 12 can be included in any appropriate housing or packaging. Various methods of manufacturing  
5 housings are described in commonly assigned U.S. Patent Application Serial No. 08/800,037, filed February 13, 1997, and incorporated herein by reference.

Fig. 2 shows but one embodiment in the form of a card or badge 19 including a housing 11 of plastic or other suitable material supporting the device 12 and the power supply 18. In one embodiment, the front face of  
10 the badge has visual identification features such as graphics, text, information found on identification or credit cards, etc.

Fig. 3 illustrates but one alternative housing supporting the device 12. More particularly, Fig. 3 shows a miniature housing 20 encasing the device 12 and power supply 18 to define a tag which can be supported by an object  
15 (e.g., hung from an object, affixed to an object, etc.). Although two particular types of housings have been disclosed, the device 12 can be included in any appropriate housing.

If the power supply 18 is a battery, the battery can take any suitable form. Preferably, the battery type will be selected depending on weight, size,  
20 and life requirements for a particular application. In one embodiment, the battery 18 is a thin profile button-type cell forming a small, thin energy cell more commonly utilized in watches and small electronic devices requiring a thin profile. A conventional button-type cell has a pair of electrodes, an anode formed by one face and a cathode formed by an opposite face. In an  
25 alternative embodiment, the power source 18 comprises a series connected pair of button type cells. Instead of using a battery, any suitable power source can be employed.

The circuitry 16 further includes a backscatter transmitter and is configured to provide a responsive signal to the interrogator 26 by radio  
30 frequency. More particularly, the circuitry 16 includes a transmitter, a receiver, and memory such as is described in U.S. Patent Application Serial Number 08/705,043.

Radio frequency identification has emerged as a viable and affordable alternative to tagging or labeling small to large quantities of items. The interrogator 26 communicates with the devices 12 via an electromagnetic link, such as via an RF link (e.g., at microwave frequencies, in one embodiment),  
5 so all transmissions by the interrogator 26 are heard simultaneously by all devices 12 within range.

If the interrogator 26 sends out a command requesting that all devices 12 within range identify themselves, and gets a large number of simultaneous replies, the interrogator 26 may not be able to interpret any of  
10 these replies. Therefore, arbitration schemes are provided.

If the interrogator 26 has prior knowledge of the identification number of a device 12 which the interrogator 26 is looking for, it can specify that a response is requested only from the device 12 with that identification number. To target a command at a specific device 12, (i.e., to initiate point-on-point  
15 communication), the interrogator 26 must send a number identifying a specific device 12 along with the command. At start-up, or in a new or changing environment, these identification numbers are not known by the interrogator 26. Therefore, the interrogator 26 must identify all devices 12 in the field (within communication range) such as by determining the identification  
20 numbers of the devices 12 in the field. After this is accomplished, point-to-point communication can proceed as desired by the interrogator 26.

Generally speaking, RFID systems are a type of multiaccess communication system. The distance between the interrogator 26 and devices 12 within the field is typically fairly short (e.g., several meters), so  
25 packet transmission time is determined primarily by packet size and baud rate. Propagation delays are negligible. In such systems, there is a potential for a large number of transmitting devices 12 and there is a need for the interrogator 26 to work in a changing environment, where different devices 12 are swapped in and out frequently (e.g., as inventory is added or  
30 removed). In such systems, the inventors have determined that the use of random access methods work effectively for contention resolution (i.e., for

dealing with collisions between devices 12 attempting to respond to the interrogator 26 at the same time).

RFID systems have some characteristics that are different from other communications systems. For example, one characteristic of the illustrated  
5 RFID systems is that the devices 12 never communicate without being prompted by the interrogator 26. This is in contrast to typical multiaccess systems where the transmitting units operate more independently. In addition, contention for the communication medium is short lived as compared to the ongoing nature of the problem in other multiaccess systems.  
10 For example, in a RFID system, after the devices 12 have been identified, the interrogator can communicate with them in a point-to-point fashion. Thus, arbitration in a RFID system is a transient rather than steady-state phenomenon. Further, the capability of a device 12 is limited by practical restrictions on size, power, and cost. The lifetime of a device 12 can often  
15 be measured in terms of number of transmissions before battery power is lost. Therefore, one of the most important measures of system performance in RFID arbitration is total time required to arbitrate a set of devices 12. Another measure is power consumed by the devices 12 during the process. This is in contrast to the measures of throughput and packet delay in other  
20 types of multiaccess systems.

Fig. 4 illustrates one arbitration scheme that can be employed for communication between the interrogator and devices 12. Generally, the interrogator 26 sends a command causing each device 12 of a potentially large number of responding devices 12 to select a random number from a  
25 known range and use it as that device's arbitration number. By transmitting requests for identification to various subsets of the full range of arbitration numbers, and checking for an error-free response, the interrogator 26 determines the arbitration number of every responder station capable of communicating at the same time. Therefore, the interrogator 26 is able to  
30 conduct subsequent uninterrupted communication with devices 12, one at a time, by addressing only one device 12.

Three variables are used: an arbitration value (AVALUE), an arbitration mask (AMASK), and a random value ID (RV). The interrogator sends an Identify command (IdentifyCmnd) causing each device of a potentially large number of responding devices to select a random  
5 number from a known range and use it as that device's arbitration number. The interrogator sends an arbitration value (AVALUE) and an arbitration mask (AMASK) to a set of devices 12. The receiving devices 12 evaluate the following equation:  $(AMASK \& AVALUE) == (AMASK \& RV)$  wherein "&" is a bitwise AND function, and wherein "==" is an equality function. If the  
10 equation evaluates to "1" (TRUE), then the device 12 will reply. If the equation evaluates to "0" (FALSE), then the device 12 will not reply. By performing this in a structured manner, with the number of bits in the arbitration mask being increased by one each time, eventually a device 12 will respond with no collisions. Thus, a binary search tree methodology is  
15 employed.

An example using actual numbers will now be provided using only four bits, for simplicity, reference being made to Fig. 4. In one embodiment, sixteen bits are used for AVALUE and AMASK. Other numbers of bits can also be employed depending, for example, on the number of devices 12  
20 expected to be encountered in a particular application, on desired cost points, etc.

Assume, for this example, that there are two devices 12 in the field, one with a random value (RV) of 1100 (binary), and another with a random value (RV) of 1010 (binary). The interrogator is trying to establish  
25 communications without collisions being caused by the two devices 12 attempting to communicate at the same time.

The interrogator sets AVALUE to 0000 (or "don't care" for all bits, as indicated by the character "X" in Fig. 4) and AMASK to 0000. The interrogator transmits a command to all devices 12 requesting that they  
30 identify themselves. Each of the devices 12 evaluate  $(AMASK \& AVALUE) == (AMASK \& RV)$  using the random value RV that the respective devices 12 selected. If the equation evaluates to "1" (TRUE),

then the device 12 will reply. If the equation evaluates to "0" (FALSE), then the device 12 will not reply. In the first level of the illustrated tree, AMASK is 0000 and anything bitwise ANDed with all zeros results in all zeros, so both the devices 12 in the field respond, and there is a collision.

5       Next, the interrogator sets AMASK to 0001 and AVALUE to 0000 and transmits an identify command. Both devices 12 in the field have a zero for their least significant bit, and  $(AMASK \& AVALUE) == (AMASK \& RV)$  will be true for both devices 12. For the device 12 with a random value of 1100, the left side of the equation is evaluated as follows (0001 & 1000)=0000. The right side is evaluated as (0001 & 1100)=0000. The left side equals the right side, so the equation is true for the device 12 with the random value of 1100. For the device 12 with a random value of 1010, the left side of the equation is evaluated as (0001 & 0000)=0000. The right side is evaluated as (0001 & 1010)=0000. The left side equals the right side, so  
10       the equation is true for the device 12 with the random value of 1010. Because the equation is true for both devices 12 in the field, both devices 12 in the field respond, and there is another collision.

      Recursively, the interrogator next sets AMASK to 0011 with AVALUE still at 0000 and transmits an Identify command.  $(AMASK \& AVALUE) == (AMASK \& RV)$  is evaluated for both devices 12. For the device 12 with a random value of 1100, the left side of the equation is evaluated as follows (0011 & 0000)=0000. The right side is evaluated as (0011 & 1100)=0000. The left side equals the right side, so the equation is true for the device 12 with the random value of 1100, so this device 12  
20       responds. For the device 12 with a random value of 1010, the left side of the equation is evaluated as (0011 & 0000)=0000. The right side is evaluated as (0011 & 1010)=0010. The left side does not equal the right side, so the equation is false for the device 12 with the random value of 1010, and this device 12 does not respond. Therefore, there is no collision, and the interrogator can determine the identity (e.g., an identification  
25       number) for the device 12 that does respond.  
30

De-recursion takes place, and the devices 12 to the right for the same AMASK level are accessed when AVALUE is set at 0010, and AMASK is set to 0011.

The device 12 with the random value of 1010 receives a command and  
5 evaluates the equation  $(AMASK \& AVALUE) == (AMASK \& RV)$ . The left side of the equation is evaluated as  $(0011 \& 0010) = 0010$ . The right side of the equation is evaluated as  $(0011 \& 1010) = 0010$ . The right side equals the left side, so the equation is true for the device 12 with the random value of 1010. Because there are no other devices 12 in the subtree, a good reply  
10 is returned by the device 12 with the random value of 1010. There is no collision, and the interrogator 26 can determine the identity (e.g., an identification number) for the device 12 that does respond.

By recursion, what is meant is that a function makes a call to itself. In other words, the function calls itself within the body of the function.  
15 After the called function returns, de-recursion takes place and execution continues at the place just after the function call; i.e. at the beginning of the statement after the function call.

For instance, consider a function that has four statements (numbered 1,2,3,4) in it, and the second statement is a recursive call.  
20 Assume that the fourth statement is a return statement. The first time through the loop (iteration 1) the function executes the statement 2 and (because it is a recursive call) calls itself causing iteration 2 to occur. When iteration 2 gets to statement 2, it calls itself making iteration 3. During execution in iteration 3 of statement 1, assume that the function does a  
25 return. The information that was saved on the stack from iteration 2 is loaded and the function resumes execution at statement 3 (in iteration 2), followed by the execution of statement 4 which is also a return statement. Since there are no more statements in the function, the function de-recurses to iteration 1. Iteration 1, had previously recursively called itself in statement  
30 2. Therefore, it now executes statement 3 (in iteration 1). Following that it executes a return at statement 4. Recursion is known in the art.

Consider the following code which can be used to implement operation of the method shown in Fig. 4 and described above.

```

Arbitrate(AMASK, AVALUE)
5      {
      collision=IdentifyCmnd(AMASK, AVALUE)
      if (collision) then
      {
        /* recursive call for left side */
10      Arbitrate((AMASK<<1)+1, AVALUE)
        /* recursive call for right side */
        Arbitrate((AMASK<<1)+1, AVALUE+(AMASK+1))
      } /* endif */
      } /* return */
15

```

The symbol "<<" represents a bitwise left shift. "<<1" means shift left by one place. Thus, 0001<<1 would be 0010. Note, however, that  
20 AMASK is originally called with a value of zero, and 0000<<1 is still 0000. Therefore, for the first recursive call, AMASK = (AMASK<<1)+1. So for the first recursive call, the value of AMASK is 0000+0001=0001. For the second call, AMASK=(0001<<1)+1=0010+1=0011. For the third recursive call, AMASK=(0011<<1)+1=0110+1=0111.

25 The routine generates values for AMASK and AVALUE to be used by the interrogator in an identify command "IdentifyCmnd." Note that the routine calls itself if there is a collision. De-recursion occurs when there is no collision. AVALUE and AMASK would have values such as the following assuming collisions take place all the way down to the bottom of the tree.

30

AVALUE	AMASK
0000	0000
0000	0001
0000	0011
0000	0111
0000	1111*
1000	1111*
0100	0111
0100	1111*
1100	1111*

This sequence of AMASK, AVALUE binary numbers assumes that there are collisions all the way down to the bottom of the tree, at which point the Identify command sent by the interrogator is finally successful so that no collision occurs. Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol “\*”. Note that if the Identify command was successful at, for example, the third line in the table then the interrogator would stop going down that branch of the tree and start down another, so the sequence would be as shown in the following table.

AVALUE	AMASK
0000	0000
0000	0001
0000	0011*
0010	0011
...	...

This method is referred to as a splitting method. It works by splitting groups of colliding devices into subsets that are resolved in turn. The



splitting method can also be viewed as a type of tree search. Each split moves the method one level deeper in the tree.

Either depth-first or breadth-first traversals of the tree can be employed. Depth first traversals are performed by using recursion, as is  
5 employed in the code listed above. Breadth-first traversals are accomplished by using a queue instead of recursion. The following is an example of code for performing a breadth-first traversal.

```
Arbitrate(AMASK, AVALUE)
10   {
      enqueue(0,0)
      while (queue != empty)
        (AMASK,AVALUE) = dequeue()
        collision=IdentifyCmnd(AMASK, AVALUE)
15      if (collision) then
        {
          TEMP = AMASK+1
          NEW_AMASK = (AMASK<<1)+1
          enqueue(NEW_AMASK, AVALUE)
20          enqueue(NEW_AMASK, AVALUE+TEMP)
        } /* endif */
      endwhile

      }/* return */
25
```

The symbol “!=” means not equal to. AVALUE and AMASK would have values such as those indicated in the following table for such code.

	AVALUE	AMASK
	0000	0000
	0000	0001
	0001	0001
5	0000	0011
	0010	0011
	0001	0011
	0011	0011
	0000	0111
10	0100	0111
	...	...

Rows in the table for which the interrogator is successful in receiving  
 15 a reply without collision are marked with the symbol “\*”.

Fig. 5 illustrates an embodiment wherein the interrogator 26 starts the  
 tree search at a selectable level of the search tree. The search tree has a  
 plurality of nodes 51, 52, 53, 54 etc. at respective levels. The size of  
 subgroups of random values decrease in size by half with each node  
 20 descended. The upper bound of the number of devices 12 in the field (the  
 maximum possible number of devices that could communicate with the  
 interrogator) is determined, and the tree search method is started at a level  
 32, 34, 36, 38, or 40 in the tree depending on the determined upper bound.  
 In one embodiment, the maximum number of devices 12 potentially capable  
 25 of responding to the interrogator is determined manually and input into the  
 interrogator 26 via an input device such as a keyboard, graphical user  
 interface, mouse, or other interface. The level of the search tree on which  
 to start the tree search is selected based on the determined maximum  
 possible number of wireless identification devices that could communicate with  
 30 the interrogator.

The tree search is started at a level determined by taking the base two logarithm of the determined maximum possible number. More particularly, the tree search is started at a level determined by taking the base two logarithm of the power of two nearest the determined maximum possible number of devices 12. The level of the tree containing all subgroups of random values is considered level zero (see Fig. 5), and lower levels are numbered 1, 2, 3, 4, etc. consecutively.

By determining the upper bound of the number of devices 12 in the field, and starting the tree search at an appropriate level, the number of collisions is reduced, the battery life of the devices 12 is increased, and arbitration time is reduced.

For example, for the search tree shown in Fig. 5, if it is known that there are seven devices 12 in the field, starting at node 51 (level 0) results in a collision. Starting at level 1 (nodes 52 and 53) also results in a collision. The same is true for nodes 54, 55, 56, and 57 in level 2. If there are seven devices 12 in the field, the nearest power of two to seven is the level at which the tree search should be started.  $\text{Log}_2 8=3$ , so the tree search should be started at level 3 if there are seven devices 12 in the field.

AVALUE and AMASK would have values such as the following assuming collisions take place from level 3 all the way down to the bottom of the tree.

AVALUE	AMASK
0000	0111
0000	1111*
1000	1111*
0100	0111
0100	1111*
1100	1111*

Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol “\*”.

In operation, the interrogator transmits a command requesting devices 12 having random values RV within a specified group of random values to respond, the specified group being chosen in response to the determined maximum number. Devices 12 receiving the command respectively determine if their chosen random values fall within the specified group and, if so, send a reply to the interrogator. The interrogator determines if a collision occurred between devices that sent a reply and, if so, creates a new, smaller, specified group, descending in the tree, as described above in connection with Fig. 4.

Fig. 6 illustrates an embodiment wherein the interrogator 26 retries on the same node that yielded a good reply. The search tree has a plurality of nodes 151, 152, 153, 154 etc. at respective levels 132, 134, 136, 138, or 140. The size of subgroups of random values decrease in size by half with each node descended.

The interrogator performs a tree search, either depth-first or breadth-first in a manner such as that described in connection with Fig. 4, except that if the interrogator determines that no collision occurred in response to an Identify command, the interrogator repeats the command at the same node. This takes advantage of an inherent capability of the devices, particularly if the devices use backscatter communication, called self-arbitration. Arbitration times can be reduced, and battery life for the devices can be increased.

When a single reply is read by the interrogator, for example, in node 152, the method described in connection with Fig. 4 would involve proceeding to node 153 and then sending another Identify command. Because a device 12 in a field of devices 12 can override weaker devices, this embodiment is modified such that the interrogator retries on the same node 152 after silencing the device 12 that gave the good reply. Thus, after receiving a good reply from node 152, the interrogator remains on node 152 and reissues the Identify command after silencing the device that first responded on node 152. Repeating the Identify command on the same node often yields other

good replies, thus taking advantage of the devices natural ability to self-arbitrate.

AVALUE and AMASK would have values such as the following for a depth-first traversal in a situation similar to the one described above in connection with Fig. 4.

	AVALUE	AMASK
	0000	0000
	0000	0001
10	0000	0011
	0000	0111
	0000	1111*
	0000	1111*
	1000	1111*
15	1000	1111*
	0100	0111
	0100	1111*
	0100	1111*
	1100	1111*
20	1100	1111*

Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol “\*”.

In operation, the interrogator transmits a command at a node, requesting that devices within the subgroup represented by the node respond. The interrogator determines if a collision occurs in response to the command and, if not, repeats the command at the same node.

In one alternative embodiment, the upper bound of the number of devices 12 in the field (the maximum possible number of devices that could communicate with the interrogator) is determined, and the tree search method is started at a level 132, 134, 136, 138, or 140 in the tree depending

on the determined upper bound. The level of the search tree on which to start the tree search is selected based on the determined maximum possible number of wireless identification devices that could communicate with the interrogator. The tree search is started at a level determined by taking the  
5 base two logarithm of the determined maximum possible number. More particularly, the tree search is started at a level determined by taking the base two logarithm of the power of two nearest the determined maximum possible number of devices 12. The level of the tree containing all subgroups of random values is considered level zero, and lower levels are  
10 numbered 1, 2, 3, 4, etc. consecutively.

In one alternative embodiment, a method involving starting at a level in the tree depending on a determined upper bound (such as the method described in the commonly assigned patent application mentioned above) is combined with a method comprising re-trying on the same node that gave a  
15 good reply, such as the method shown and described in connection with Fig. 6.

Fig. 7 illustrates an embodiment wherein levels in the tree are skipped. The inventors have determined that skipping levels in the tree, after a collision caused by multiple devices 12 responding, reduces the number of  
20 subsequent collisions without adding significantly to the number of no replies. In real-time systems, it is desirable to have quick arbitration sessions on a set of devices 12 whose unique identification numbers are unknown. Level skipping reduces the number of collisions, both reducing arbitration time and conserving battery life on a set of devices 12.

Thus, Fig. 7 illustrates a binary search tree 232 being defined for a  
25 tree search method similar to the tree search method described in connection with Fig. 4. The tree 232 has multiple levels 234, 236, 238, 240, and 242 representing subgroups of the multiple devices 12. The number of devices in a subgroup in one level 234, 236, 238, 240, and 242 is half of the number  
30 of devices in the next higher level 234, 236, 238, 240, and 242. Although only five levels are shown, if more bits are employed, (e.g., sixteen bits or an integer multiple of eight or sixteen bits for each of AMASK and AVALUE),

there will of course be more levels. The tree search method illustrated in Fig. 7 employs level skipping wherein at least one level of the tree is skipped.

A first predetermined number of bits, e.g. sixteen or an integer multiple of eight or sixteen bits, are established to be used as unique identification numbers. Respective devices 12 are provided with unique identification numbers respectively having the first predetermined number of bits, in addition to their random values RV. For example, such unique identification numbers are stored in memory in the respective devices 12.

A second predetermined number of bits are established to be used for the random values RV. The devices 12 are caused to select random values, RV. This is done, for example, by the interrogator 26 sending an appropriate command. Respective devices choose random values independently of random values selected by the other devices 12. Random number generators are known in the art.

The interrogator transmits a command requesting devices 12 having random values RV within a specified group of random values to respond, using a methodology similar to that described in connection with Fig. 4, except that levels are skipped. Four subsets of random values, instead of two, are probed when moving down the tree and skipping a level. This means that instead of eliminating half of the remaining devices 12 and re-trying, after a collision, the interrogator eliminates three quarters of the remaining devices 12 and re-tries (by sending a command). In other words, a new specified group is created that is one quarter of the set of random values of the previous group.

Each devices 12 that receives the command determines if its chosen random value falls within the specified group by evaluating the equation  $(AMASK \& AVALUE) == (AMASK \& RV)$  and, if so, sends a reply to the interrogator. The reply includes the random value of the replying device 12 and the unique identification number of the device 12. The interrogator determines if a collision occurred between devices that sent a reply and, if

so, creates a new, smaller, specified group, by moving down the tree, skipping a level.

In the illustrated embodiment, every other level is skipped. In alternative embodiments, more than one level is skipped each time.

5       The trade off that must be considered in determining how many (if any) levels to skip with each decent down the tree is as follows. Skipping levels reduces the number of collisions, thus saving battery power in the devices 12. Skipping deeper (skipping more than one level) further reduces the number of collisions. The more levels that are skipped, the greater the  
10 reduction in collisions. However, skipping levels results in longer search times because the number of queries (Identify commands) increases. The more levels that are skipped, the longer the search times. The inventors have determined that skipping just one level has an almost negligible effect on search time, but drastically reduces the number of collisions. If more  
15 than one level is skipped, search time increases substantially.

The inventors have determined that skipping every other level drastically reduces the number of collisions and saves battery power without significantly increasing the number of queries.

After receiving a reply without collision from a device 12, the  
20 interrogator 26 can send a command individually addressed to that device by using its now known random value or its now known unique identification number.

The above described code for depth-first traversal is modified to provide for level skipping by increasing the number of recursive calls as  
25 shown below. For example, the above described code for depth-first traversal is replaced with code such as the following to provide for depth-first traversal employing level skipping.



```

Arbitrate(AMASK, AVALUE)
{
  collision=IdentifyCmnd(AMASK, AVALUE)
  if (collision) then
5      {
        TEMP = AMASK+1
        NEW_AMASK = (AMASK<<2)+3
        Arbitrate(NEW_AMASK, AVALUE)
        Arbitrate(NEW_AMASK, AVALUE+TEMP)
10      Arbitrate(NEW_AMASK, AVALUE+2*TEMP)
        Arbitrate(NEW_AMASK, AVALUE+3*TEMP)
      } /* endif */
    } /* return */

```

15 AVALUE and AMASK would have values such as those indicated in the following table for such code.

	AVALUE	AMASK
	0000	0000
20	0000	0011
	0000	1111*
	0100	1111*
	1000	1111*
	1100	1111*
25	0001	0011
	0001	1111*
	0101	1111*
	1001	1111*
	1101	1111*
30	0010	0011
	0010	1111*
	0110	1111*
	1010	1111*
	1110	1111*
35	...	...

Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol “\*”.

Similarly, the code provided above for breadth-first traversal can be readily modified to employ level skipping. Instead of inserting two items into the queue each time through the loop, four items are inserted into the queue each time through the loop. For either breadth-first traversal or depth-first traversal, AMASK will be shifted by two bits instead of one, and AVALUE will take on twice as many different values as in the case where level skipping is not employed.

Another arbitration method that can be employed is referred to as the “Aloha” method. In the Aloha method, every time a device 12 is involved in a collision, it waits a random period of time before retransmitting. This method can be improved by dividing time into equally sized slots and forcing transmissions to be aligned with one of these slots. This is referred to as “slotted Aloha.” In operation, the interrogator asks all devices 12 in the field to transmit their identification numbers in the next time slot. If the response is garbled, the interrogator informs the devices 12 that a collision has occurred, and the slotted Aloha scheme is put into action. This means that each device 12 in the field responds within an arbitrary slot determined by a randomly selected value. In other words, in each successive time slot, the devices 12 decide to transmit their identification number with a certain probability.

The Aloha method is based on a system operated by the University of Hawaii. In 1971, the University of Hawaii began operation of a system named Aloha. A communication satellite was used to interconnect several university computers by use of a random access protocol. The system operates as follows. Users or devices transmit at any time they desire. After transmitting, a user listens for an acknowledgment from the receiver or interrogator. Transmissions from different users will sometimes overlap in time (collide), causing reception errors in the data in each of the contending messages. The errors are detected by the receiver, and the receiver sends a negative acknowledgment to the users. When a negative acknowledgment is

received, the messages are retransmitted by the colliding users after a random delay. If the colliding users attempted to retransmit without the random delay, they would collide again. If the user does not receive either an acknowledgment or a negative acknowledgment within a certain amount of time, the user "times out" and retransmits the message.

There is a scheme known as slotted Aloha which improves the Aloha scheme by requiring a small amount of coordination among stations. In the slotted Aloha scheme, a sequence of coordination pulses is broadcast to all stations (devices). As is the case with the pure Aloha scheme, packet lengths are constant. Messages are required to be sent in a slot time between synchronization pulses, and can be started only at the beginning of a time slot. This reduces the rate of collisions because only messages transmitted in the same slot can interfere with one another. The retransmission mode of the pure Aloha scheme is modified for slotted Aloha such that if a negative acknowledgment occurs, the device retransmits after a random delay of an integer number of slot times.

Aloha methods are described in a commonly assigned patent application (attorney docket number MI40-089) naming Clifton W. Wood, Jr. as an inventor, titled "Method of Addressing Messages and Communications System," filed concurrently herewith, and incorporated herein by reference.

In another alternative embodiment, an Aloha method (such as the method described in the commonly assigned patent application mentioned above) is combined with determining the upper bound on a set of devices and starting at a level in the tree depending on the determined upper bound, such as by combining an Aloha method with the method shown and described in connection with Fig. 5. For example, in one embodiment, devices 12 sending a reply to the interrogator 26 do so within a randomly selected time slot of a number of slots.

In one alternative embodiment, an Aloha method (such as the method described in the commonly assigned patent application mentioned above) is

combined with a method involving re-trying on the same node that gave a good reply, such as the method shown and described in connection with Fig. 6.

In one alternative embodiment, an Aloha method is combined with level skipping, such as the level skipping shown and described in connection  
5 with Fig. 7. For example, in one embodiment, devices 12 sending a reply to the interrogator 26 do so within a randomly selected time slot of a number of slots.

CLAIMS

1. A method of establishing wireless communications between an interrogator and individual ones of multiple wireless identification devices, the method comprising utilizing a tree search method to establish communications without collision between the interrogator and individual ones of the multiple wireless identification devices, a search tree being defined for the tree search method, the tree having multiple levels respectively representing subgroups of the multiple wireless identification devices, the method further comprising starting the tree search at a selectable level of the search tree.

2. A method in accordance with claim 1 and further comprising determining the maximum possible number of wireless identification devices that could communicate with the interrogator, and selecting a level of the search tree based on the determined maximum possible number of wireless identification devices that could communicate with the interrogator.

3. A method in accordance with claim 2 and further comprising starting the tree search at a level determined by taking the base two logarithm of the determined maximum possible number, wherein the level of the tree containing all subgroups is considered level zero, and lower levels are numbered consecutively.

4. A method in accordance with claim 2 and further comprising starting the tree search at a level determined by taking the base two logarithm of the determined maximum possible number, wherein the level of the tree containing all subgroups is considered level zero, and lower levels are numbered consecutively, and wherein the maximum number of devices in a subgroup in one level is half of the maximum number of devices in the next higher level.

5. A method in accordance with claim 2 and further comprising starting the tree search at a level determined by taking the base two logarithm of the power of two nearest the determined maximum possible number, wherein the level of the tree containing all subgroups is considered  
5 level zero, and lower levels are numbered consecutively, and wherein the maximum number of devices in a subgroup in one level is half of the maximum number of devices in the next higher level.

6. A method in accordance with claim 1 wherein the wireless  
10 identification device comprises an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.

7. A method of addressing messages from an interrogator to a  
15 selected one or more of a number of communications devices, the method comprising:

establishing a first predetermined number of bits to be used as unique identification numbers, and establishing for respective devices unique identification numbers respectively having the first predetermined number of  
20 bits;

establishing a second predetermined number of bits to be used for random values;

causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other  
25 devices;

determining the maximum number of devices potentially capable of responding to the interrogator;

transmitting a command from the interrogator requesting devices having random values within a specified group of random values to respond, the  
30 specified group being chosen in response to the determined maximum number;

receiving the command at multiple devices, devices receiving the command respectively determining if the random value chosen by the device falls within the specified group and, if so, sending a reply to the interrogator; and

5 determining using the interrogator if a collision occurred between devices that sent a reply and, if so, creating a new, smaller, specified group.

8. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices in accordance  
10 with claim 7 wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply.

9. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices in accordance  
15 with claim 7 wherein sending a reply to the interrogator comprises transmitting the random value of the device sending the reply.

10. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices in accordance  
20 with claim 7 wherein sending a reply to the interrogator comprises transmitting both the random value of the device sending the reply and the unique identification number of the device sending the reply.

11. A method of addressing messages from an interrogator to a  
25 selected one or more of a number of communications devices in accordance with claim 7 wherein, after receiving a reply without collision from a device, the interrogator sends a command individually addressed to that device.

12. A communications system comprising an interrogator, and a plurality of wireless identification devices configured to communicate with the interrogator in a wireless fashion, the respective wireless identification devices having a unique identification number, the interrogator being configured to  
5 employ a tree search technique to determine the unique identification numbers of the different wireless identification devices so as to be able to establish communications between the interrogator and individual ones of the multiple wireless identification devices without collision by multiple wireless identification devices attempting to respond to the interrogator at the same  
10 time, wherein the interrogator is configured to start the tree search at a selectable level of the search tree.

13. A communications system in accordance with claim 12 wherein the tree search technique is a binary tree search technique.

15

14. A communications system in accordance with claim 12 wherein the wireless identification device comprises an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.

20

15. A system comprising:  
an interrogator configured to communicate to a selected one or more of a number of RFID devices;  
a plurality of RFID devices, respective devices being configured to  
25 store unique identification numbers respectively having a first predetermined number of bits, the first predetermined number being an integer multiple of sixteen, respective devices being further configured to store a second predetermined number of bits to be used for random values, the second predetermined number being an integer multiple of sixteen, respective devices  
30 being configured to select random values independently of random values selected by the other devices;



the interrogator being configured to transmit an identify command requesting a response from devices having random values within a specified group of a plurality of possible groups or random values, the specified group being less than or equal to the entire set of random values, the plurality of possible groups being organized in a binary tree defined by a plurality of nodes at respective levels, wherein the maximum size of groups of random values decrease in size by half with each node descended, wherein the specified group is below a node on a level of the tree selected based on a predetermined number based on the maximum number of devices known to be capable of communicating with the interrogator;

devices receiving the command respectively being configured to determine if their chosen random values fall within the specified group and, only if so, send a reply to the interrogator, wherein sending a reply to the interrogator comprises transmitting both the random value of the device sending the reply and the unique identification number of the device sending the reply;

the interrogator being configured to determine if a collision occurred between devices that sent a reply and, if so, create a new, smaller, specified group using a level of the tree different from the level used in previously transmitting an identify command, the interrogator transmitting an identify command requesting devices having random values within the new specified group of random values to respond; and

the interrogator being configured to send a command individually addressed to a device after communicating with a device without a collision.

25

16. A system in accordance with claim 15 wherein the interrogator is configured to input and store the predetermined number.

17. A system in accordance with claim 15 wherein the devices are configured to respectively determine if their chosen random values fall within a specified group and, if so, send a reply, upon receiving respective identify commands.

30

18. A system in accordance with claim 17 wherein the interrogator is configured to determine if a collision occurred between devices that sent a reply in response to respective identify commands and, if so, create further new specified groups and repeat the transmitting of the identify command  
5 requesting devices having random values within a specified group of random values to respond using different specified groups until all responding devices are identified.

19. A method of establishing wireless communications between an  
10 interrogator and individual ones of multiple wireless identification devices, the method comprising utilizing a tree search method to attempt to identify individual ones of the multiple wireless identification devices so as to be able to perform communications, without collision, between the interrogator and individual ones of the multiple wireless identification devices, a search tree  
15 being defined for the tree search method, the tree having multiple nodes respectively representing subgroups of the multiple wireless identification devices, wherein the interrogator transmits a command at a node, requesting that devices within the subgroup represented by the node respond, wherein the interrogator determines if a collision occurs in response to the command  
20 and, if not, repeats the command at the same node.

20. A method in accordance with claim 19 wherein, if a collision occurs in response to the first mentioned command, the interrogator sends an command at a different node.  
25

21. A method in accordance with claim 19 wherein a subgroup contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is not within communications range  
30 of the interrogator does not respond to the command.

22. A method in accordance with claim 19 wherein a subgroup contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is within communications range of  
5 the interrogator responds to the command.

23. A method in accordance with claim 19 wherein a device in a subgroup changes between being within communications range of the interrogator and not being within communications range, over time.

10

24. A method in accordance with claim 19 wherein the wireless identification device comprises an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.

15

25. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices, the method comprising:

establishing a first predetermined number of bits to be used as unique  
20 identification numbers, and establishing for respective devices unique identification numbers respectively having the first predetermined number of bits;

establishing a second predetermined number of bits to be used for random values;

25 causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other devices;

interrogator transmitting a command from the interrogator requesting devices having random values within a first specified group of random values  
30 to respond;

receiving the command at multiple devices, devices receiving the command respectively determining if the random value chosen by the device

falls within the first specified group and, if so, sending a reply to the interrogator; and

determining using the interrogator if a collision occurred between devices that sent a reply and, if so, creating a second specified group smaller  
5 than the first specified group; and, if not, again transmitting a command requesting devices having random values within the first specified group of random values to respond.

26. A method of addressing messages from an interrogator to a  
10 selected one or more of a number of communications devices in accordance with claim 25 wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply.

27. A method in accordance with claim 25 wherein one of the first  
15 and second specified groups contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is not within communications range of the interrogator does not respond to the interrogator.

20

28. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices in accordance with claim 25 wherein, after receiving a reply without collision from a device, the interrogator sends a command individually addressed to that device.

25

29. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices, the method comprising:

establishing for respective devices unique identification numbers respectively having a first predetermined number of bits;

5 establishing a second predetermined number of bits to be used for random values;

causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other devices;

10 transmitting a command using the interrogator requesting devices having random values within a specified group of a plurality of possible groups of random values to respond, the specified group being equal to or less than the entire set of random values, the plurality of possible groups being organized in a binary tree defined by a plurality of nodes at respective  
15 levels, wherein the maximum size of groups of random values decrease in size by half with each node descended;

receiving the command at multiple devices, devices receiving the command respectively determining if their chosen random values fall within the specified group and, only if so, sending a reply to the interrogator,  
20 wherein sending a reply to the interrogator comprises transmitting the unique identification number of the device sending the reply;

determining using the interrogator if a collision occurred between devices that sent a reply and, if so, creating a new, smaller, specified group using a level of the tree different from the level used in the interrogator  
25 transmitting, the interrogator transmitting a command requesting devices having random values within the new specified group of random values to respond; and, if not, the interrogator re-transmitting a command requesting devices having random values within the first mentioned specified group of random values to respond; and

30 if a reply without collision is received from a device, the interrogator subsequently sending a command individually addressed to that device.

30. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim 29 wherein the first mentioned specified group contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is not within communications range of the interrogator does not respond to the transmitting of the command or the re-transmitting of the command.

31. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim 29 wherein the first mentioned specified group contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is within communications range of the interrogator responds to the transmitting of the command and the re-transmitting of the command.

32. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim 29 wherein a device in the first mentioned specified group is capable of changing between being within communications range of the interrogator and not being within communications range of the interrogator over time.

33. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim 29 wherein the devices respectively comprise an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.

34. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim 29 and further comprising, after the interrogator transmits a command requesting devices having random values within the new specified group of  
5 random values to respond:

devices receiving the command respectively determining if their chosen random values fall within the new smaller specified group and, if so, sending a reply to the interrogator.

10 35. A communications system comprising an interrogator, and a plurality of wireless identification devices configured to communicate with the interrogator in a wireless fashion, the interrogator being configured to employ tree searching to attempt to identify individual ones of the multiple wireless identification devices, so as to be able to perform communications without  
15 collision, between the interrogator and individual ones of the multiple wireless identification devices, the interrogator being configured to follow a search tree, the tree having multiple nodes respectively representing subgroups of the multiple wireless identification devices, the interrogator being configured to transmit a command at a node, requesting that devices within the subgroup  
20 represented by the node respond, the interrogator further being configured to determine if a collision occurs in response to the command and, if not, to repeat the command at the same node.

36. A communications system in accordance with claim 35 wherein  
25 the interrogator is configured to send a command at a different node if a collision occurs in response to the first mentioned command.

37. A communications system in accordance with claim 35 wherein a subgroup contains both a device that is within communications range of the  
30 interrogator, and a device that is not within communications range of the interrogator.

38. A communications system in accordance with claim 35 wherein a subgroup contains both a device that is within communications range of the interrogator, and a device that is not within communications range of the interrogator, and wherein the device that is within communications range of  
5 the interrogator responds to the command.

39. A communications system in accordance with claim 35 wherein a device in a subgroup is movable relative to the interrogator so as to be capable of changing between being within communications range of the  
10 interrogator and not being within communications range.

40. A communications system in accordance with claim 35 wherein the wireless identification device comprises an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the  
15 receiver and modulator.

41. A system comprising:  
an interrogator configured to communicate to a selected one or more of a number of communications devices;  
20 a plurality of communications devices;  
the devices being configured to select random values, wherein respective devices choose random values independently of random values selected by the other devices;  
the interrogator being configured to transmit a command requesting  
25 devices having random values within a specified group of a plurality of possible groups of random values to respond, the specified group being less than the entire set of random values, the plurality of possible groups being organized in a binary tree defined by a plurality of nodes at respective levels, the specified group being defined as being at one of the nodes, wherein the  
30 size of groups of random values decrease in size by half with each node descended;



devices receiving the command being configured to respectively determine if their chosen random values fall within the specified group and, only if so, send a reply to the interrogator, wherein sending a reply to the interrogator comprises transmitting the unique identification number of the  
5 device sending the reply;

the interrogator being configured to determine if a collision occurred between devices that sent a reply and, if so, create a new, smaller, specified group using a different level of the tree, the interrogator being configured to transmit a command requesting devices having random values within the new  
10 specified group of random values to respond; and, if not, the interrogator being configured to re-transmit a command requesting devices having random values within the first mentioned specified group of random values to respond; and

if a reply without collision is received from a device, the interrogator  
15 being configured to send a command individually addressed to that device.

42. A system in accordance with claim 41 wherein the first mentioned specified group contains both a device that is within communications range of the interrogator, and a device that is not within  
20 communications range of the interrogator.

43. A system in accordance with claim 41 wherein a device in the first mentioned specified group is capable of changing between being within communications range of the interrogator and not being within  
25 communications range of the interrogator over time.

44. A system in accordance with claim 41 wherein the respective devices comprise an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.

30

45. A method of establishing wireless communications between an interrogator and individual ones of multiple wireless identification devices, the method comprising utilizing a tree search method to establish communications without collision between the interrogator and individual ones of the multiple  
5 wireless identification devices, a search tree being defined for the tree search method, the tree having multiple levels representing subgroups of the multiple wireless identification devices, the number of devices in a subgroup in one level being half of the number of devices in the next higher level, the tree search method employing level skipping wherein at least one level of the tree  
10 is skipped.

46. A method in accordance with claim 45 wherein the wireless identification device comprises an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and  
15 modulator.

47. A method of addressing messages from an interrogator to a selected one or more of a number of communications devices, the method comprising:  
20 establishing a first predetermined number of bits to be used as unique identification numbers, and establishing for respective devices unique identification numbers respectively having the first predetermined number of bits;  
establishing a second predetermined number of bits to be used for  
25 random values;  
causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other devices;  
transmitting a command from the interrogator requesting devices having  
30 random values within a specified group of random values to respond;  
receiving the command at multiple devices, devices receiving the command respectively determining if the random value chosen by the device

falls within the specified group and, if so, sending a reply to the interrogator;  
and

determining using the interrogator if a collision occurred between  
devices that sent a reply and, if so, creating a new, smaller, specified group  
5 that is one quarter of the first mentioned specified group.

48. A method of addressing messages from an interrogator to a  
selected one or more of a number of communications devices in accordance  
with claim 47 wherein sending a reply to the interrogator comprises  
10 transmitting the unique identification number of the device sending the reply.

49. A method of addressing messages from an interrogator to a  
selected one or more of a number of communications devices in accordance  
with claim 47 wherein sending a reply to the interrogator comprises  
15 transmitting the random value of the device sending the reply.

50. A method of addressing messages from an interrogator to a  
selected one or more of a number of communications devices in accordance  
with claim 47 wherein sending a reply to the interrogator comprises  
20 transmitting both the random value of the device sending the reply and the  
unique identification number of the device sending the reply.

51. A method of addressing messages from an interrogator to a  
selected one or more of a number of communications devices in accordance  
25 with claim 47 wherein, after receiving a reply without collision from a device,  
the interrogator sends a command individually addressed to that device.

52. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices, the method comprising:
- establishing for respective devices unique identification numbers respectively having a first predetermined number of bits, the first  
5 predetermined number being a multiple of sixteen;
  - establishing a second predetermined number of bits to be used for random values, the second predetermined number being a multiple of sixteen;
  - causing the devices to select random values, wherein respective devices choose random values independently of random values selected by the other  
10 devices;
  - transmitting from the interrogator a command requesting devices having random values within a specified group of a plurality of possible groups of random values to respond, the specified group being less than or equal to the entire set of random values, the plurality of possible groups being organized  
15 in a binary tree having a plurality of levels, wherein groups of random values decrease in size by half with each level;
  - receiving the command at multiple of the devices, the devices receiving the command respectively determining if the random value chosen by the device falls within the specified group and, only if so, sending a reply to the  
20 interrogator, wherein sending a reply to the interrogator comprises transmitting both the random value of the device sending the reply and the unique identification number of the device sending the reply;
  - determining using the interrogator if a collision occurred between devices that sent a reply and, if so, creating a new, smaller, specified group  
25 using a level of the tree different from the level used in the interrogator transmitting, wherein at least one level of the tree is skipped, the interrogator transmitting a command requesting devices having random values within the new specified group of random values to respond; and
  - if a reply without collision is received from a device, the interrogator  
30 subsequently sending a command individually addressed to that device.

53. A method of addressing messages from an interrogator to a selected one or more of a number of RFID devices in accordance with claim 52 wherein exactly one level is skipped.

5 54. A communications system comprising an interrogator, and a plurality of wireless identification devices configured to communicate with the interrogator in a wireless fashion, the respective wireless identification devices having a unique identification number, the interrogator being configured to employ a tree search technique to determine the unique identification  
10 numbers of the different wireless identification devices so as to be able to establish communications between the interrogator and individual ones of the multiple wireless identification devices without collision by multiple wireless identification devices attempting to respond to the interrogator at the same time, wherein levels of the tree are skipped in some instances.

15

55. A communications system in accordance with claim 54 wherein the tree search technique is a binary tree search technique.

56. A communications system in accordance with claim 54 wherein  
20 the wireless identification device comprises an integrated circuit including a receiver, a modulator, and a microprocessor in communication with the receiver and modulator.

57. A system comprising:  
25 an interrogator configured to communicate to a selected one or more of a number of communications devices;  
a plurality of communications devices;  
the devices being configured to select random values, wherein respective devices choose random values independently of random values  
30 selected by the other devices;  
the interrogator being configured to transmit a command requesting devices having random values within a specified group of a plurality of

possible groups of random values to respond, the specified group being less than or equal to the entire set of random values, the plurality of possible groups being organized in a binary tree having a plurality of levels, wherein groups of random values decrease in size by half with each level descended;

5        devices receiving the command being configured to respectively determine if their chosen random values fall within the specified group and, if so, send a reply to the interrogator; and, if not, not send a reply; and

         the interrogator being configured to determine if a collision occurred between devices that sent a reply and, if so, create a new, smaller, specified

10    group by descending at least two levels in the tree.

58.    A system in accordance with claim 57 wherein the random values have a predetermined number of bits.

15        59.    A system in accordance with claim 57 wherein respective devices are configured to store unique identification numbers of a predetermined number of bits.

         60.    A system comprising:

20        an interrogator configured to communicate to a selected one or more of a number of RFID devices;

         a plurality of RFID devices, respective devices being configured to store unique identification numbers respectively having a first predetermined number of bits, the first predetermined number being an integer multiple of

25        sixteen, respective devices being further configured to store a second predetermined number of bits to be used for random values, the second predetermined number being an integer multiple of sixteen, respective devices being configured to select random values independently of random values selected by the other devices;

30        the interrogator being configured to transmit an identify command requesting devices having random values within a specified group of random

values to respond, the specified group being less than or equal to the entire set of random values;

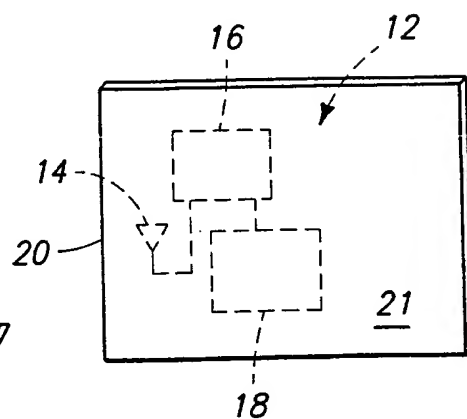
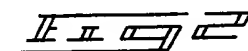
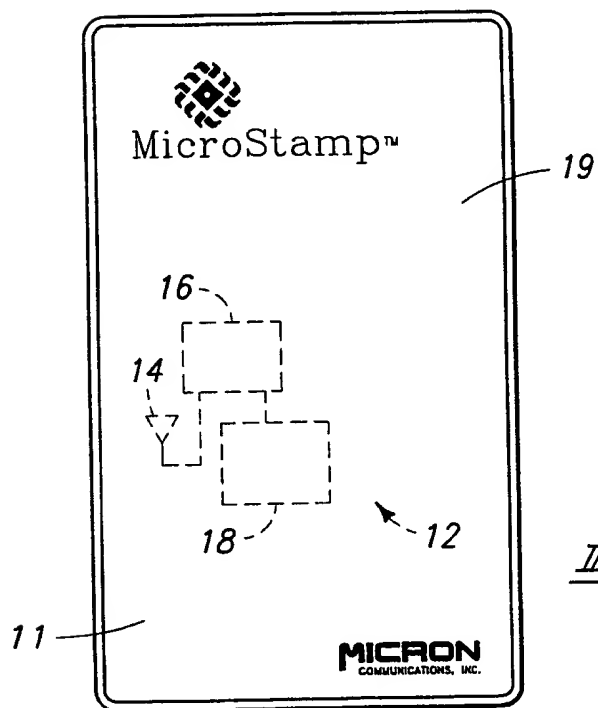
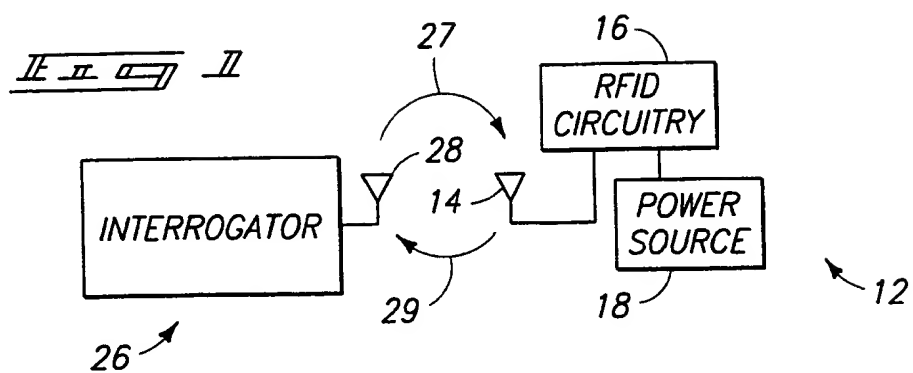
devices receiving the command respectively being configured to determine if their chosen random values fall within the specified group and,  
5 only if so, send a reply to the interrogator, wherein sending a reply to the interrogator comprises transmitting both the random value of the device sending the reply and the unique identification number of the device sending the reply;

the interrogator being configured to determine if a collision occurred  
10 between devices that sent a reply and, if so, create a new, smaller, specified group using a level of the tree different from the level used in previously transmitting an identify command, wherein at least one level of the tree is skipped, the interrogator transmitting an identify command requesting devices having random values within the new specified group of random values to  
15 respond; and

the interrogator being configured to send a command individually addressed to a device after communicating with a device without a collision.

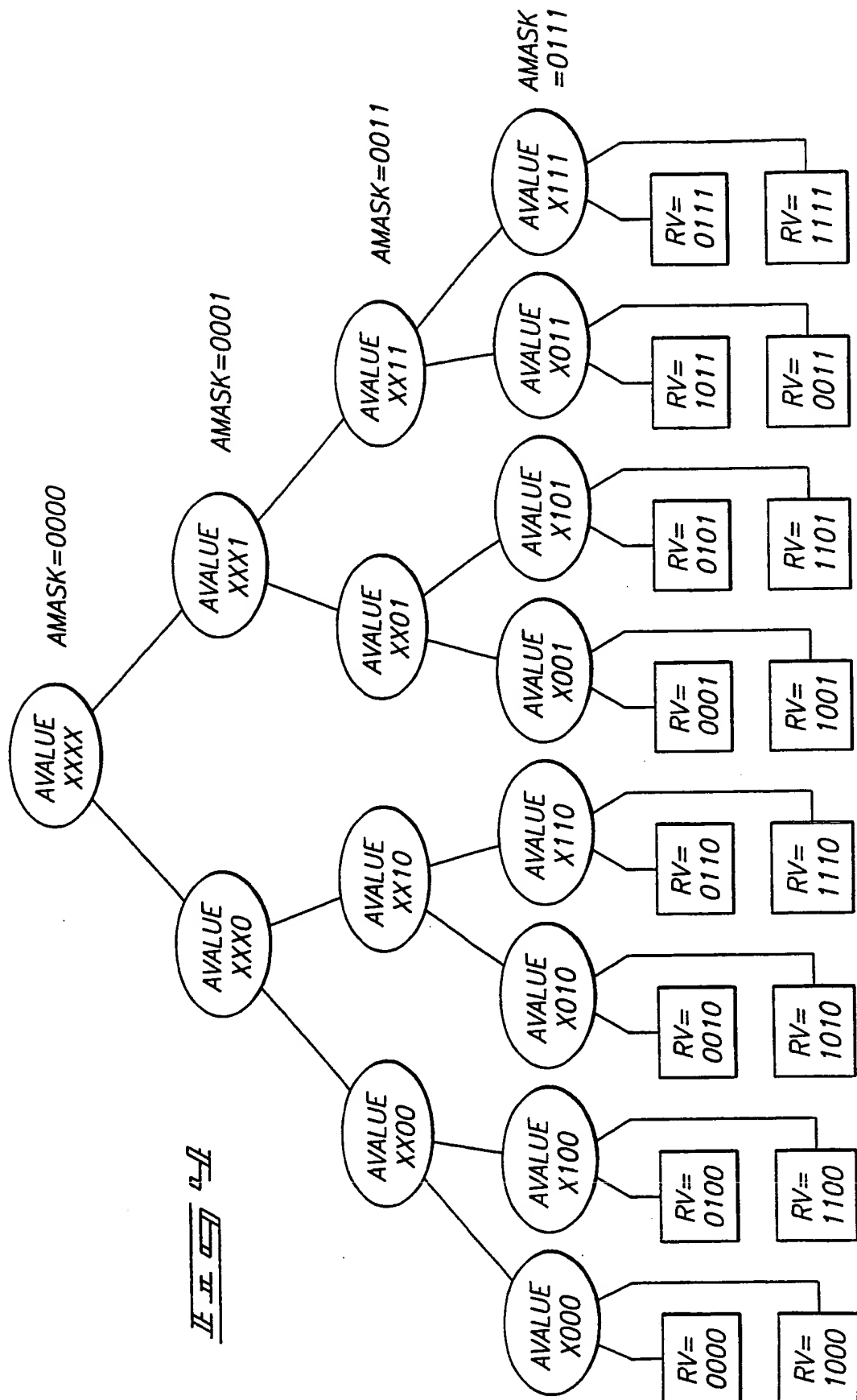
61. A system in accordance with claim 60 wherein the interrogator  
20 is configured to skip exactly one level when creating the new, smaller, specified group.

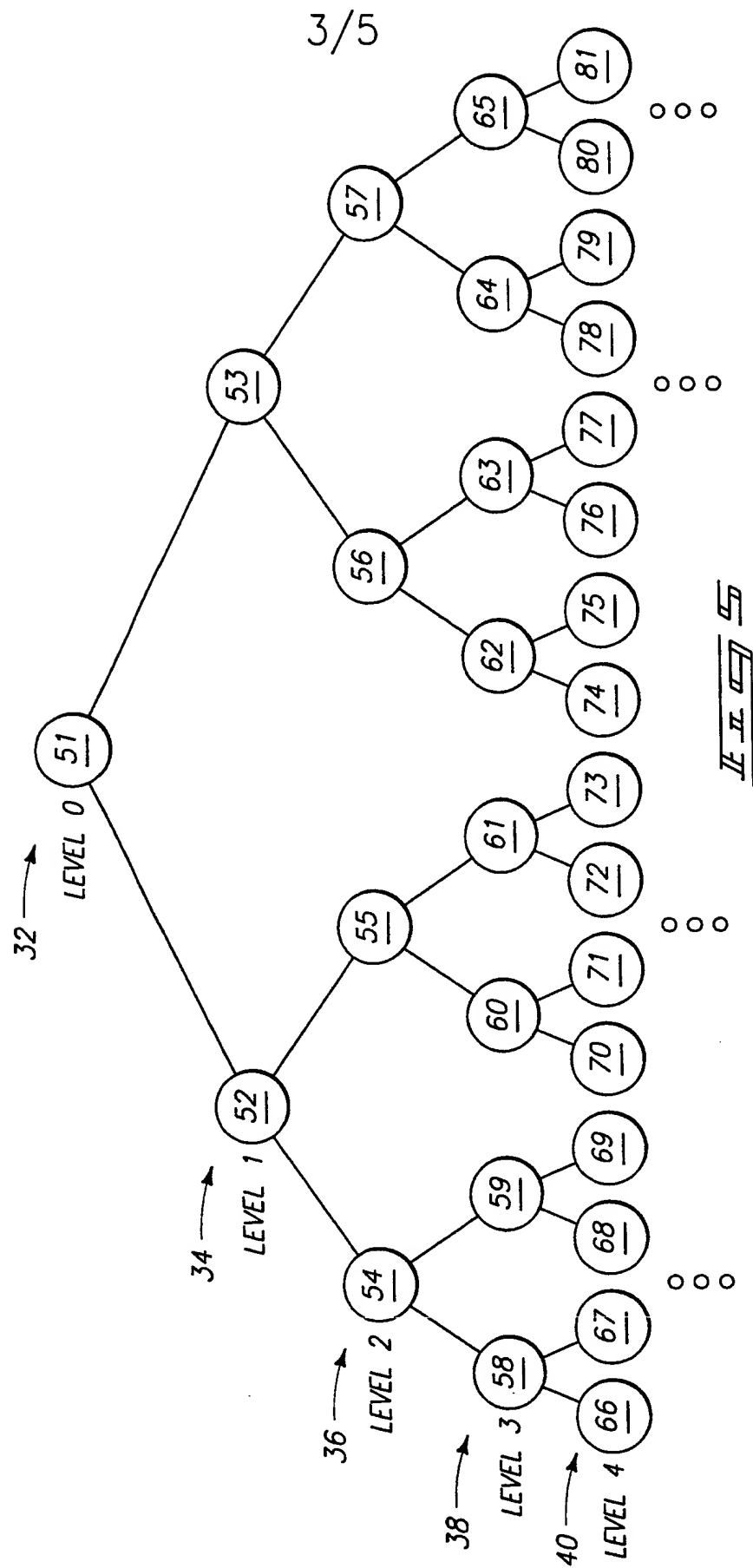
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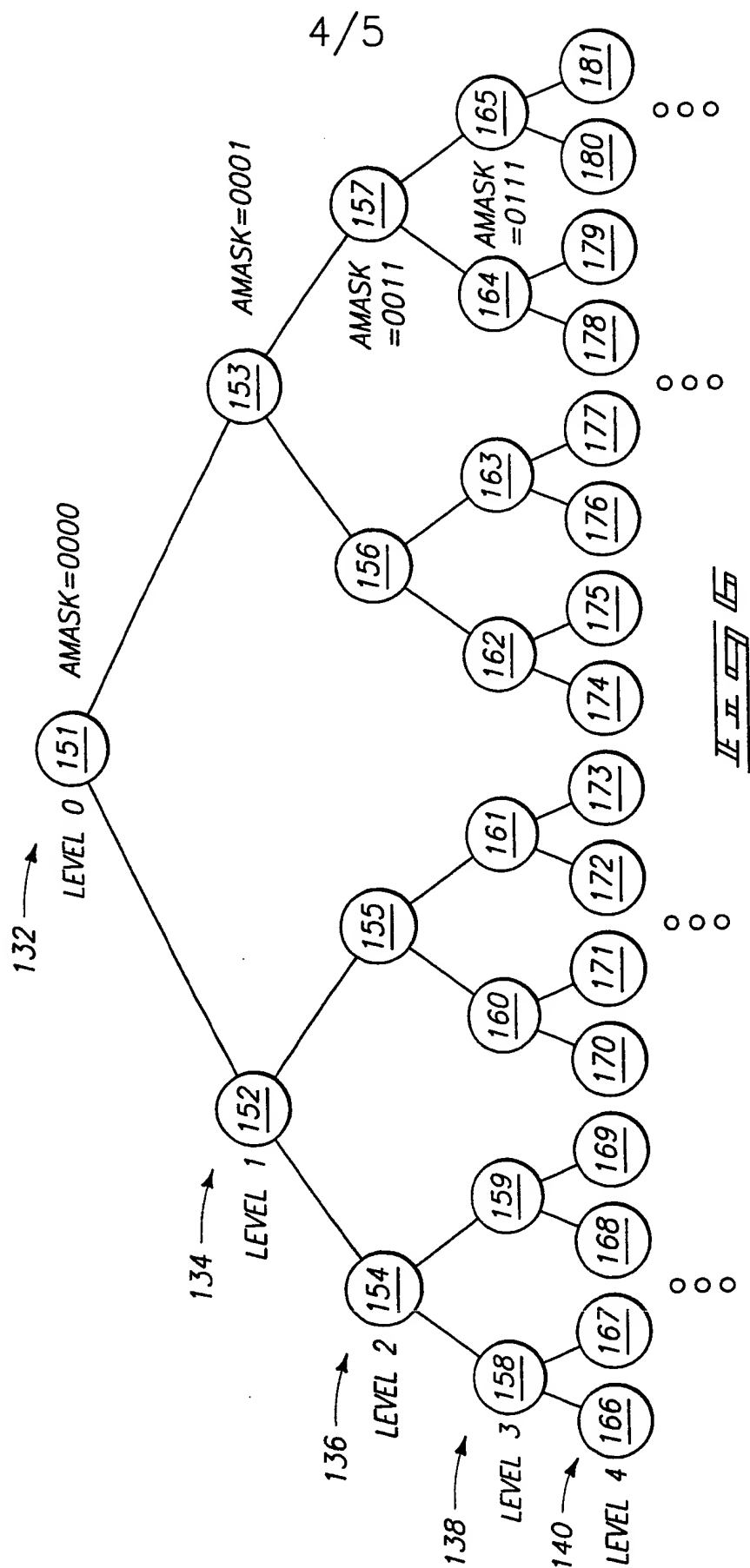


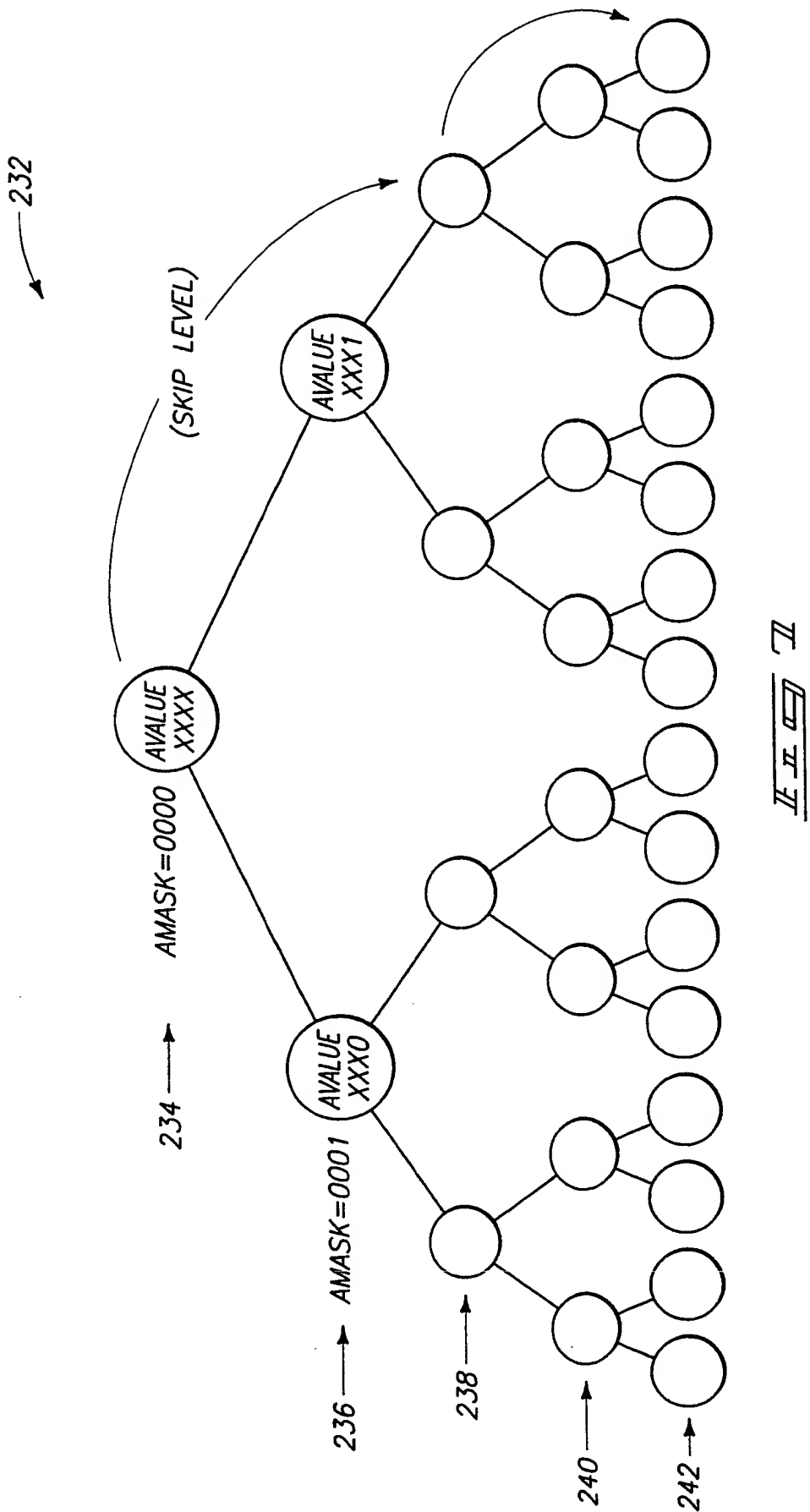


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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/02568

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 6 H04L12/28 G06K7/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04L G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>US 5 365 551 A (SNODGRASS CHARLES K ET AL) 15 November 1994 (1994-11-15) cited in the application</p> <p>column 13, line 67 - column 15, line 35 column 17, line 7 - column 19, line 63 figure 12</p> <p>---</p> <p>-/--</p>	<p>1,7,12, 15,19, 25,29, 35,41, 45,47, 52,54, 57,60</p>

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search

20 July 1999

Date of mailing of the international search report

03/08/1999

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Ströbeck, A

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/02568

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>WO 97 48216 A (AT &amp; T WIRELESS SERVICES INC) 18 December 1997 (1997-12-18)</p> <p>page 7, line 26 - page 8, line 27 -----</p>	<p>1, 7, 12, 15, 19, 25, 29, 35, 41, 45, 47, 52, 54, 57, 60</p>

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/02568

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5365551 A	15-11-1994	US 5583850 A	10-12-1996
		US 5787174 A	28-07-1998
		US 5841770 A	24-11-1998
WO 9748216 A	18-12-1997	EP 0904646 A	31-03-1999

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